



Electrical Modeling and Analysis of Human Respiratory System

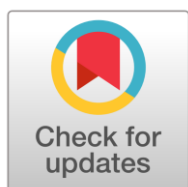
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Abstract: The human respiratory system mainly consists of four parts namely trachea, main bronchi, bronchioles and alveoli respectively. The alveoli in the lungs are responsible for the transfer of oxygen and carbon-dioxide through capillaries blood vessels leading to the pulmonary vein. A person cannot breathe properly during Chronic Obstructive Pulmonary Disease (COPD) due to abnormal transfer of oxygen and carbon-dioxide. Artificial ventilation is recommended for a person who suffers from COPD with no breathing or abnormal breathing, to manually preserve intact brain function. So, the blood oxygen level required for the person should be continuously monitored using pulse oximeter and controlled automatically using artificial ventilation. Hence, in this paper human respiratory system is modelled as analogies electrical model by using RLC parameters. The analogous electrical model parameters are represented as resistance, inheritance and compliance respectively. Using this analogous electrical model of human respiratory system, time domain and stability analysis are performed to identify COPD condition.

Keywords: Electrical analogies model, Respiratory system, Time domain analysis, Stability analysis, Bio-control, Chronic Obstructive Pulmonary Disease (COPD).

1. Introduction

The human respiratory system mainly consists of four parts namely trachea, main bronchi, bronchioles and alveoli [1-4]. Trachea is also known as windpipe; the tube diameter is one inch and length of the tube is 4 inches. The trachea begins just below the speech organ (voice box) and runs down behind the sternum. The trachea branches into two parts namely main left and right bronchi. Bronchus is an airway which conducts air to the lungs. The bronchioles are numerous tubes in the lung, which are divided from the main bronchi. For a healthy person around 480 million alveoli are present in each lung. Alveoli are small balloon shaped structures meant for oxygen and carbon-dioxide transfer between the alveoli

and blood vessels referred to as capillaries. A person cannot breathe properly during Chronic Obstructive Pulmonary Disease (COPD) due to abnormal transfer of oxygen and carbon-dioxide [5]. Two major types of COPD are bronchitis and emphysema. Bronchitis involves a long cough in the lungs along with thick mucus due to inflammation in bronchial tubes. The flu virus, bacterial infection, exposure to tobacco smoke, dust, fumes, vapors, and air pollution are the major causes for bronchitis. Emphysema involves thinning and destruction of the alveoli. Cigarette smoking, deficiency of an enzyme called alpha-1-antitrypsin, air pollution, heredity and ageing are the major causes for emphysema. Artificial ventilation is

2. Electrical Model of Respiratory System



In Fig. 2., $V(t)$ represents respiratory pressure and $I(t)$ represents airflow. In Fig. 1., trachea is represented as R_t and L_t in Fig. 2. denoting airway resistance and inertance of trachea, to mimic the resistance to airflow in the tracheo tree and visco-elastic property of tissue in trachea. In Fig. 1., main left and right bronchi is represented as R_{b1} and L_{b1} (left bronchus); R_{b2} and L_{b2} (right bronchus) in Fig. 2. denoting airway resistance and inertance of main bronchi, to mimic the resistance to airflow in the bronchial tree and visco-elastic property of tissue in bronchi. In Fig. 1. bronchioles are representing as R in Fig. 2. denoting airway resistance of bronchioles, to mimic the resistance of airflow in the bronchioles. In Fig. 1. alveoli are representing as C_b in Fig. 2. denoting alveolar compliance, to mimic the pulmonary compliance (storage and transfer of airflow). From Fig. 2. the equivalent admittance (transfer function model) is derived as follows,

Using transfer function shown in Eq. (1), various time domain and stability analysis are performed in sections III and IV respectively.

The time domain analysis using the parameter as in TABLE. 1., is performed using unit step function (representing unit air

pressure) and the corresponding airflow is shown in Fig. 3. From Fig. 3., it is observed that during inhalation process for a unit air pressure the maximum air flow (oxygen transferred to capillary veins) is 0.0842.

Table 1. Parameters of transfer function model

S.No	Parameter	Value
1	Rt (cm H ₂ O s/L)	4.5
2	Lt (cm s ² /H ₂ O L)	0.043
3	Rb1 (cm H ₂ O s/L)	9
4	Lb1 (cm s ² /H ₂ O L)	0.17
5	Rb2 (cm H ₂ O s/L)	9
6	Lb2 (cm s ² /H ₂ O L)	0.17
7	R (cm H ₂ O s/L)	0.5
8	Cb (L cm/ H ₂ O kg)	0.01

Similarly, time domain analysis is performed for an average person by changing the alveoli compliance Cb as 0.001, and the corresponding airflow is shown in Fig. 4. From Fig. 4., it is observed that during inhalation process for a unit air pressure the maximum air flow (oxygen transferred to capillary veins) is 0.0522. That is 38.01% reduction in airflow is observed for a average person with comparison to Fig. 3 (healthy person).

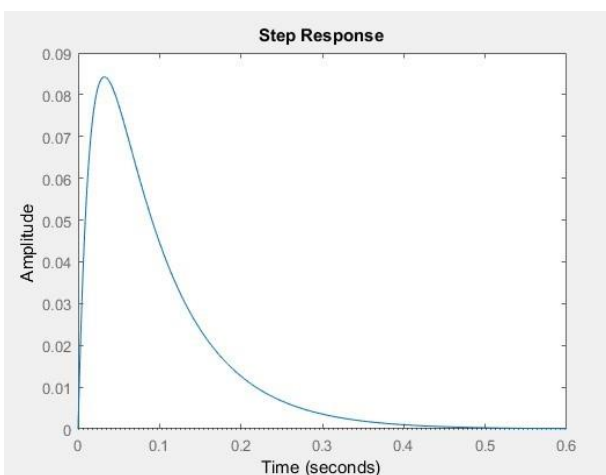


Fig 3. Airflow of typical healthy human (during inhalation)

Similarly, time domain analysis is performed for a person affected with COPD (emphysema) by changing the alveoli compliance Cb as 0.0001, and the corresponding airflow is shown in Fig. 5. From

Fig. 5., it is observed that during inhalation process for a unit air pressure the maximum air flow (oxygen transferred to capillary veins) is 0.0229. That is 56.13% reduction in airflow is observed for a person with extreme emphysema condition with comparison to Fig. 4 (average person).

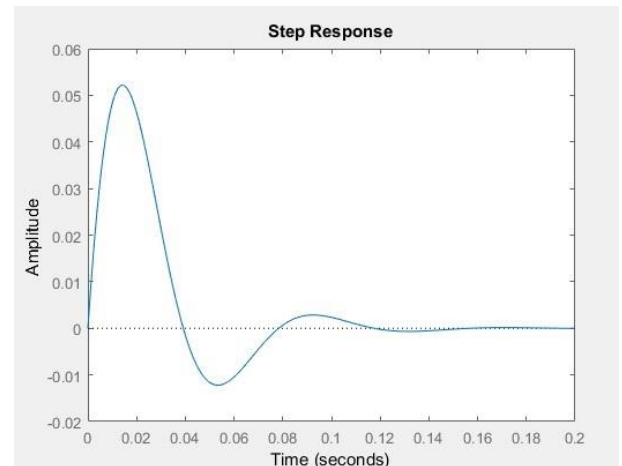


Fig 4. Airflow of average human (during inhalation)

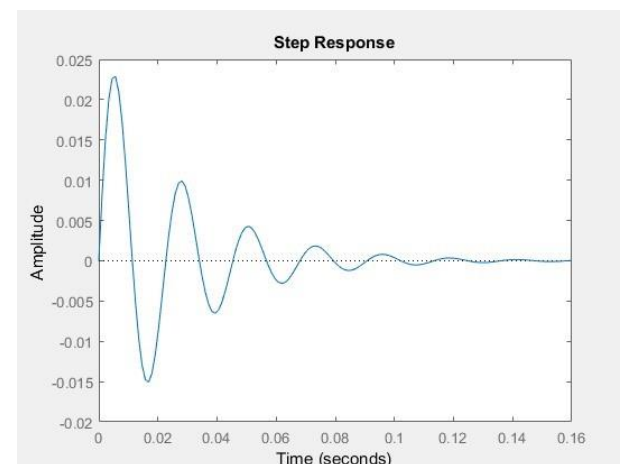


Fig 5. Airflow of human affected with emphysema

Similarly time domain analysis is performed for a person affected with COPD (bronchitis) by changing the airway resistance of main bronchi Rb1 and Rb2 (left and right) as 12.6, and the corresponding airflow is shown in Fig. 6.

From Fig. 6., it is observed that during inhalation process for a unit air pressure the maximum air flow (oxygen transferred to capillary veins) is 0.0483. That is 7.47% reduction in airflow is observed for a person with extreme bronchitis condition with

comparison to Fig. 4 (average person). It is obvious fact that bronchitis condition is less severe than emphysema as it observed that the airflow reduction is less when compare to emphysema affected person.

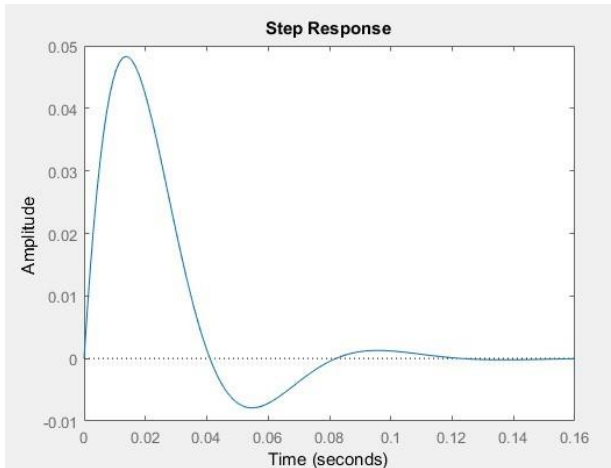


Fig 6. Airflow of human affected with bronchitis (during inhalation)

4. Stability Analysis

The stability analysis using the parameter as in TABLE. I., is performed by analyzing the root locus as shown in Fig. 7.

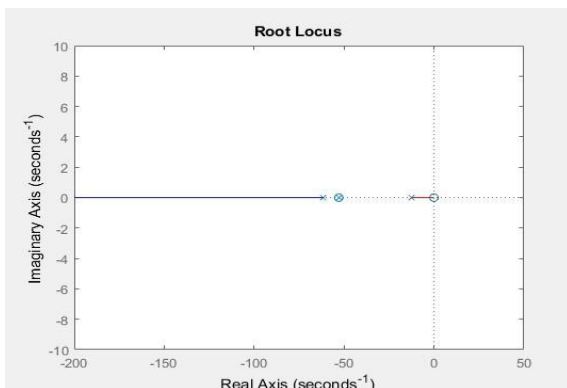


Fig 7. Root locus of typical healthy human

From Fig. 7., it can be observed that for any open loop gain K the system remains stable. In contrary it is observed from Fig. 8., that for an average person the maximum permissible open loop gain K is 889. But in irony it observed from Fig. 9., that for a person suffering with severe emphysema the dominant poles are shifted near to the imaginary axis. That is the person with prolonged emphysema would end with the unstable region (fatal or critical

condition). In addition, from Fig. 10., it is observed that no significant variation is observed for a person with severe bronchitis. Hence it is reinforced that emphysema condition is more severe than bronchitis.

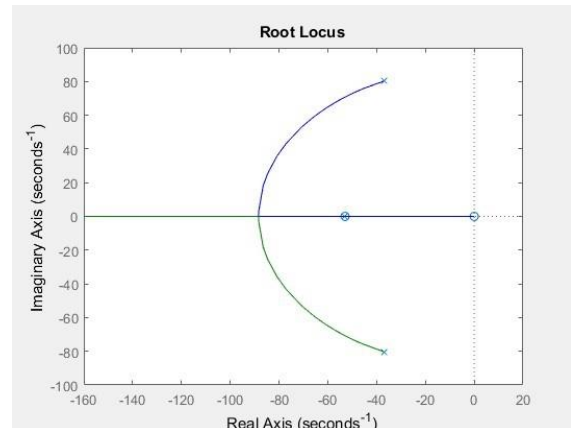


Fig 8. Root locus of average human

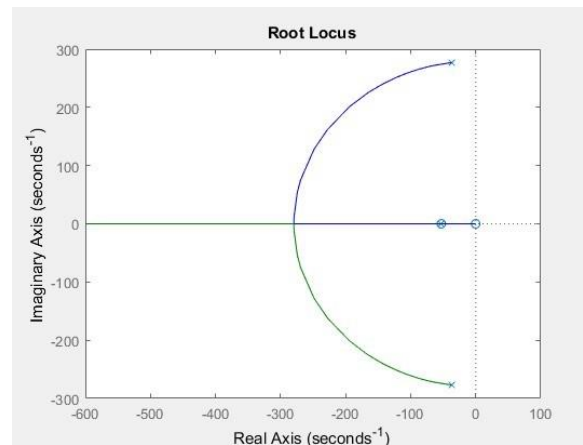


Fig 9. Root locus of human affected with emphysema

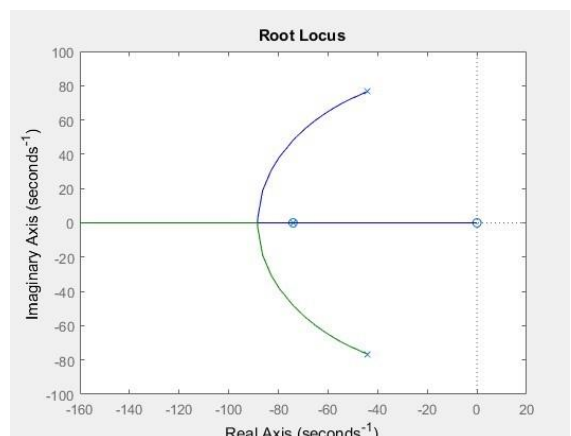


Fig 10. Root locus of human affected with bronchitis

5. Conclusion

This paper describes the need for electrical analogous model of human respiratory system by emphasizing the importance of identification and analysis of COPD. In particular this paper describes the various parameters of the electrical model, subsequently the transfer function model was developed. Using the developed transfer function model, time domain and stability analysis were performed and reported. The analysis reveals that an abundant reduction in airflow is observed with a person suffering from extreme emphysema which might result in critical condition. In addition, relatively less reduction in airflow is observed for a person suffering from severe bronchitis. This analysis can be further extended to other COPD conditions which might help in developing suitable controllers to aid person with pulmonary disorders.

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